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When knowledge married capital: the birth of academic enterprise

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Abstract

Purpose – This paper aims to investigate knowledge-capital relationship through tracking the history of knowledge commercialization.

Design/methodology/approach – Theoretical exploration, historical evidence and interviews are used in this research. Firstly it recalls the convergence of academic knowledge and industrial capital. Then the knowledge-capital marriage is observed. Finally, the paper discusses the impact of the marriage on future enterprise development.

Findings – The combination of knowledge and capital is inevitable; the knowledge-capital marriage is the origin of contemporary academic enterprise; the future enterprise will more rely on knowledge-capital combination.

Originality/value – This study is helpful to policymaking: to promote the combination of knowledge and capital in less developed countries or regions, achieving knowledge-capital interaction in innovation system.

Keywords Knowledge, Capital, Entrepreneurial university, Knowledge commercialization, Academic enterprise, Knowledge management

Paper type Research paper

Introduction

The contemporary entrepreneurial university, exhibiting the combination of academic knowledge and industrial capital, was foreseen by a seventeenth century British Government official who envisioned scientific research as a driver of economic advance. In time stolen from his duties as King James's Attorney General and Lord Chancellor, Francis Bacon projected the, "reconstruction of the sciences" (Bacon, [1620]1980, p. 15). In his Manifesto for construction of a knowledge-based society, Bacon outlined a program of methodological, disciplinary and institutional reforms to take science from the individualistic practice of syllogistic reasoning to a collective mode of inductive experimentation. The objective was not knowledge alone, "experiments of Light," but useful knowledge, "experiments of Fruit," not "human intellect left to its own course," but encompassed within "a regular system of operations" that would produce a steady stream of innovation (Bacon, [1620]1980, p. 12). To realize this objective Bacon proposed the creation of a scientific research institute as a font of theoretical and practical knowledge. In sharp contrast to the small-scale organizational framework of his era, Bacon outlined a multifaceted scheme with diverse equipments, trained personnel and experimental facilities. He called this knowledge production and transfer institution "Solomon's House" after the Biblical King.

This was a new departure in a society whose knowledge was rooted in the past. Medieval universities were repositories of ancient knowledge and training grounds for ecclesiastical, legal and a few other professions. Science had an independent origin in the societies of natural philosophers, often under royal patronage, who investigated the

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workings of nature and certified the validity of inventions (Hahn, 1971). Although seventeenth century science in England exemplified to a considerable degree the idea of science in the service of practical purposes (30-60 percent in one estimate), its organizational framework was weak (Merton, 1938). As we shall see in this paper, experimental science only became incorporated in the university once reliable methodologies, that made research teachable, were achieved. Occasional instances of useful discoveries and their translation into wider use were then extrapolated into a distinctive academic format. This academic tributary of applied research and technical training is becoming mainstream even as the meandering stream of basic research produces a torrent of technology. The growing realization of the economic potential of university-based research is causing a revision in some traditional beliefs and practices concerning the role of the university in society. This realignment of purpose promises to be as significant and far reaching as the late nineteenth and early twentieth century transformation of the classical teaching college into the research university. As the research university assumes economic development functions, its image as an "ivory tower" fades and a new image, tied to technological innovation, is projected.

Technology grew up as a parallel enterprise, rooted in craft practices. Industry was traditionally the province of practical people, with little if any theoretical knowledge or training. The origin of the contemporary economic utilization of knowledge lies in the systematization of craft practices during the early years of the industrial revolution by workers and manufacturers alike (Landes, 1969). Knowledge was transmitted through the generations by an apprenticeship system and transformed through improvements in manufacturing practices into capital. The emergence of the professional engineering role during the eighteenth century and the incorporation of engineering training in the university during the nineteenth century was a step towards transforming craft practices into formal academic disciplines (Layton, 1971). The development of academic engineering research during the early twentieth century and the application of scientific principles to engineering practices expanded the process of transforming knowledge into economic goods (Noble, 1986). As these fields of endeavor came together the seeds of knowledge-based economic development were planted. In the following, we discuss the emerging symbiosis between knowledge and capital, opening up the way to make universities into innovation actors and academic entrepreneurs.

Some early instances of the commercialization of knowledge

Opportunities to translate basic research into industrial applications were always present, yet few scientists took advantage of them. The few who did were a distinct and unusual minority. Scientists' attitudes, arising from the notion of science as a gentlemanly activity undertaken by amateurs, precluded commercial involvement. Rarely did a scientist in the seventeenth century have to make a living as a scientist. Those who pursued natural philosophy typically had independent resources. Robert K. Merton has called Robert Hooke, who held a paid position at the Royal Society, the first "professional scientist." Before university positions offered incomes sufficient to support a scientific career, Hooke attempted to make a living from science. "His agreement with Brouncker, Boyle and Moray held that in return for three quarters of the profits derived therefrom (not exceeding 4,000)" he would:

> [. . .] discover to them the whole of his invention to measure the parts of Time at Sea as exactly as they are at Land by the Pendulum Clocks invented by Monsieur Huygens! (Merton, 1938, p. 524).

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The failure to obtain an Act of Parliament guaranteeing royalties from ship owners prevented the agreement from being realized.

The seeds of European academic entrepreneurship germinated from the development of academic research in the sciences, especially chemistry in mid nineteenth century Germany. Some instances have been noted of ill paid chemistry professors initiating commercial ventures to supplement their incomes. Soon after his appointment as Professor of Chemistry at Wuerzburg, Johann Georg Pickel formed a partnership with Seitz, an entrepreneur. They obtained government permission to establish a factory and produced Glauber's salts, magnesium carbonate potash and acetic acid. A second factory was opened but neither was commercially successful and both soon closed. These ventures and similar ones begun by Professor Tromsdorff in 1811 and Professors Hermbstaedt and Erdman in 1817 did not attempt to develop new technology based on scientific theory or experimentation. Chemist's technical skills were merely used to supervise the production process.

There also are other academic knowledge-based entrepreneurship instances which can be found in early nineteenth century Germany. The most notable were those of Professor Justus Von Liebig (of Giessen University) and John Bennett Lawes, a British experimental farmer. During his career Liebig undertook consulting work and research contracts from chemical manufacturers. Although the payments were small they helped subsidize his research and support the assistants he employed in his university laboratory. Liebig's laboratory in a former military barracks on the university's outskirts scaled up scientific training and incorporated it into the university on a systematic basis (Rossiter, 1975). In the laboratory, the professor and his assistants could lead a larger group of students through an ordered sequence of lectures and experiments, thus training chemists more efficiently.

Careful attention to developing curricula led to improvements in analytical techniques, speeding up the research process. For example, Liebig reported that with new techniques 400 analyses could be completed in the time it formerly took for 20. The student-inventor appeared as part of the invention of the academic chemistry laboratory where students were instructed to perform different sets of analyses, using common techniques. Instead of only doing analyses of experiments that had already been accomplished, new tasks were assigned. Some of the new knowledge that was produced included results with practical consequences. Liebig saw the possibility of commercializing these results and took steps to found firms. One of these efforts to market a liver extract was moderately successful while another in agricultural fertilizers, based on flawed chemical theory, was not. In an early commercial venture, in 1824, after analyzing a mineral springs at the request of the Hessian Ministry of Finance, Liebig recommended that several inorganic chemicals be produced from the springs. The ministry established a factory under Professor Liebig's technical supervision. But Liebig had underestimated the capital requirements of the project. When the Ministry of Finance refused to invest additional funds he abandoned the venture in 1831, having received little compensation for his efforts.

One entrepreneurial effort stands out from these mundane ventures. Liebig, in association with James Muspratt, the British chemical manufacturer, founded the Patent Mineral Manure Company in England to produce an artificial fertilizer. The product was based upon a theory of plant growth that Liebig developed after collating various studies. He theorized that plant growth could be sustained by inorganic materials and

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that the addition of nitrogen to fertilizer was unnecessary since it was available from the air. He also held that fertilizers should be insoluble so that they would not be washed away by rain. Jean-Babtiste Bossingault, John Bennett Lawes and Joseph Henry Gilbert disputed Liebig. They argued, to the contrary, that plant growth was dependent upon both organic and inorganic materials, in varying proportions, and that the solubility of fertilizer was essential so that plants could absorb it.

As a result of this controversy "patent manure" was subjected to considerable scrutiny for theoretical as well as practical reasons. Lawes, a British landowner and experimental farmer collaborated with Gilbert, a PhD from Liebig's own laboratory, to compare different fertilizers using test plots. In 1846 they fertilized a plot with "patent manure" but found that no significant increase in wheat production was obtained from the addition of minerals. Patent manure was insoluble and did not seep into the ground to be absorbed by plants. Instead, it formed a white film on the ground that had no effect on plant growth. Lawes soon developed his own fertilizer formulae, patenting "Superphosphate of Lime," and marketing it as "J.B. Lawes Patent Manure."

Liebig believed in the power of theory to produce practical results and did not conduct agricultural experiments to revise the formula. While the basic concept of artificial fertilizers underlying his "patent manure" was eventually found to have merit, the substitution of polemical attacks on critics for development research doomed the product and the company to failure. Nevertheless, Liebig's fertilizer venture represented a significant precursor of contemporary efforts of academic scientists to use theoretical knowledge to originate marketable products. His various entrepreneurial ventures also prefigured some contemporary pitfalls to successful business creation by academic scientists: underestimation of capital requirements and insufficient developmental research.

Attempts to commercialize knowledge in seventeenth century England mostly remained at the level of negotiations between researchers and potential investors that did not come to fruition. However, early nineteenth century efforts in Germany appeared to show more promise. Some ventures led to production but only very limited amounts of capital was available for knowledge ventures. Government funded efforts were confined to commercializing existing knowledge, utilizing academics as repositories of knowledge and technical skills. A private, foreign funded, venture was more ambitious but unfortunately its product was fatally flawed. These early individual idiosyncratic ventures apparently did not inspire other academics to follow in their path nor were any organizational structures established, either by government or university to systematically promote the commercialization of knowledge.

When knowledge met capital

Bacon's seventeenth century vision began to be seriously realized with the founding of industrial laboratories and graduate education in the second half of the nineteenth century. British chemist Henry Perkin's discovery of artificial dyestuffs was developed into an industry in Germany. Perkin's small-scale laboratory was scaled up into a formally organized effort with specific objectives and expected outcomes. This industrial laboratory model was transferred to industries that had gown up from incremental improvements in production processes based on close observations of anomalies that occurred while making glass and steel and then analyzing and reproducing them. As scientific knowledge was applied to systematizing invention, there was a desire to control the results while releasing the knowledge to promote future innovation, led to the

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adaptation of traditional state grants of monopolies to encourage the development of natural resources to be applied to intellectual resources, as well.

The transformation of scientific knowledge into economic activity is a fundamental social invention. The first step in the knowledge-capital relation is to secure knowledge as private property. The second step is to maintain the value of that knowledge and the third step is to renew and increase its value. By its nature knowledge is evanescent and temporary, since it is always in principle and practice replaceable by new knowledge. Thus, property in knowledge with potential economic value must be quickly captured in order to secure value from it. Indeed, traditional means of securing the economic value of knowledge such as patents and copyrights make the temporal quality of knowledge an essential feature of their terms by specifying specific time periods. An alternative pathway to a knowledge-capital relation is to translate the knowledge into marketable product and either gain consumer recognition before competitors appear or, if arriving later, make a sufficient impact, either by tying the new product to an existing framework, as Microsoft did with Explorer, thus overwhelming first mover Netscape, or making sufficient improvements so that the first mover is superseded or as Apple achieved with the I phone, at least making it into a significant choice among several alternatives.

Licensing to firms that will produce and market may follow the initial strategy of securing property in knowledge, based on the patenting and copyrighting mechanisms, when the inventor or holder of the invention does not plan to market the technology itself. Agile firms who produce and market themselves typically follow the second strategy of securing first or second mover advantage.

A third strategy is based on firm formation, with a view either to sale of the firm to another firm or growing a large-scale independent entity, with a view to creation of equity via the stock market. Following this strategy, knowledge is transformed into equity capital by some scientists acting as entrepreneurs or as partners of entrepreneurs in founding firms in the USA and Europe and by universities taking an entrepreneurial role in China (Zhou and Peng, 2008). Older industrial corporations are also finding new products and production processes by linking themselves to academic research groups through industrial liaison programs or by going through the technology transfer office to secure a license.

Patenting and copyrighting are legal processes that allow the first step in knowledge-capital relation to be achieved. Certainly there are difficulties even in the use of a patent to secure property in an invention as inventions can be reverse engineered and the same result achieved by a different route. It is even more difficult to achieve the second and third stages of knowledge-capital relation of knowledge through the patent process even though a renewal may be obtained and additional protective patents granted. These steps typically involve an updating and revision of the original knowledge and by their very nature tend to require organizational continuity. This has become especially evident in the copyrighting of software where unless the original program is maintained and improved; it soon loses its value. If it is widely used program maintenance and upgrading soon requires a collective effort, even if the original production of the program did not. The originator's choice soon becomes one of whether to drop out of involvement in maintenance turn the effort over to an existing organization or form a new organization. Thus, capital formation is facilitated by the wish to make useful knowledge easily available. As we shall see, simply giving knowledge away freely has its pitfalls.

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The idea that culture could be transformed into capital has been traced to a comment of Auguste Comte's on the origins of capital in labor (Gouldner, 1979). Thus, capital has been defined as a produced object used to make salable utilities "[. . .] whose public goal is increased economic productivity but whose latent function is to increase the incomes and social control of those possessing it" (Gouldner, 1979, p. 22). Therefore, culture, including science, becomes capital when it generates a stream of income. Nevertheless, it is the motives and intentions of the users that is crucial to determining whether something is an item of "consumption" or "capital" for, "Nothing is capital unless used with the intention of producing something economically valuable [. . .]" (Gouldner, 1979, p. 23). As professors and university administrators take account of the economic potential of research on campus and orient themselves to its disposition, academic science is transformed from a cultural artifact consumed by other scientists into a valuable object or commodity that can be utilized to generate future income.

Three phases of development of culture as an organized activity of artists, intellectuals and scientists have been identified and an incipient fourth phase may be discerned. The first phase is characterized by a patronage system in which individual philanthropists support creative activity in the arts and sciences. In the second phase cultural workers become entrepreneurs and sell their work to the public. Finally, in a third phase culture becomes part of economic and political institutions and the cultural worker becomes an employee again (Mills, 1963). Academic science is being transformed along similar lines to other areas of culture. In the first stage, scientists conduct their research primarily as individuals or through collaboration, with philanthropic support, obtained directly or indirectly, through support of their university by wealthy individuals. A second stage is based on government support of university research groups while a third stage is characterized by employment contracts with corporations, governments and not for profit organizations. The founding of independent galleries by artists, theatres and performance groups and firms by scientists is the nucleus of a fourth stage in which cultural workers re-take control of their productive resources.

The enhanced use of IT has had contradictory effects on the ability of cultural workers to own and control their tools of production, reducing cost and scale of some devices while others, like search engines and "clouds" replicate the organizational scale of the mainframe era. The organizational effects of technological change are similarly contradictory, allowing decentralization and recentralization at one and the same time. The bureaucratization of academic science has been underway for some time. In his classic essay "Science as a vocation" Max Weber, a founder of modern sociology, noted that the material condition of scientists in German and American universities in 1918 was still heavily dependent upon teaching. Although the formats of academic organization were strikingly different, a hierarchical chair system in Germany and a more egalitarian departmental system in the USA, in the two countries the status of younger scholars was similar in that they were primarily teachers rather than researchers.

This situation changed as science in both countries grew in scale with research carried out in large institutes "[. . .] which cannot be managed without very considerable funds" (Weber, 1946). In the university young scientists were subordinated to senior researchers – bureaucratized – and made dependent upon them for access to the tools of research – proletarianized. However, in the USA, and increasingly elsewhere, academic creativity has been insured by allowing assistant professors to direct their own research groups, with responsibility to obtain support. The increasing length of

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post-doctoral studies and the ever-smaller proportion of PhD's that are able to attain tenure track academic positions is a counterweight to this positive trend. Nevertheless, this blockage has encouraged its own solution: firm-formation undertaken by younger cohorts of PhD's as well as more established academics, thus providing an outlet for PhD production and a safety valve to regulate the uneven growth of research funding.

Originating as sporadic subventions from public and private sources, funding of academic research has grown into a massive enterprise, with specialized rules and organizational routines. A unique feature of this process is that the recipients of these funds play a significant role in the decision-making process of who is funded through so-called "peer review" procedures. Researchers and the organizations within which they operate have become highly dependent upon these external sources; even as they largely control who gets the funds. However, the amounts available vary with economic cycles and national priorities and are largely out of researcher's control. Although the increase or decrease of funding certainly has an effect on academic and other institutions, such trends can just as easily rigidify existing structures, expanding or contracting them along existing lines, as well as inducing their reform.

That knowledge met capital affects the material conditions of scientists in the universities as well as the inward calling of science. When scientific knowledge is appropriated, whether by scientists or others, to generate income science itself is transformed from a cultural process that consumes the surplus of a society into a productive force that generates new income out of an aspect of culture. In recent years moneyed capital has come to be seen as constituting only part of the whole of capital, with elements of culture viewed as constituting a form of capital as well (Bordieu, 1986). Multiple forms of capital have been identified in addition to economic capital; such as intellectual, social and cultural capitals that each has their own form of value. Nevertheless, capitals are transmutable and may be turned from one form into another with increasing alacrity. Designing organizations to achieve this purpose was the next step in the knowledge-capital relation. In Germany, there was a long tradition of the application of academic knowledge in privately conducted chemical firms. The linkage perceived between scientific research and economic prosperity provides the legitimating theme for this relationship between knowledge and capital.

Invention was systematized within academia and industry through establishment of parallel organizations, research units that then interacted with each other. Industrial laboratories were founded, often by drawing an academic consultant into the firm as its founding director, initially to improve existing products and then as a source of new products and then new product lines. Schools of engineering and technology were also founded in parallel to traditional colleges at schools, like Harvard and Yale, which were growing into full-fledged universities during the late nineteenth century. Thus, an important part of engineering research and training was incorporated into the university, an institution that had increasingly become avowedly non-economic in its values and norms (Reich, 1985). The involvement of academic scientists, who had largely separated themselves from engineering in the late nineteenth century through development of an ideology and practice of basic research, was a further step in the drawing of knowledge producers into economic activities (Hounshell, 1984).

When the practical manifestations of academic discovery manifest themselves almost immediately, it is not surprising that theoretical and entrepreneurial potentialities become intertwined. Thus, the first successful insertion of foreign DNA in

a host microorganism in 1973 was quickly followed from 1976 by the founding of small entrepreneurial firms to make industrial applications of this new genetic technique in the production of new drugs and chemicals (Office of Technology Assessment, 1984). This confluence of objectives also transforms the meaning of traditional forms of scientific recognition. The intersection of scientific credit with pecuniary advantage occurs as article publication in a prestigious journal may also advance the interests of a firm. A biotech firm founder recently asked that his presentation to a public investor's forum be "embargoed" from press coverage, lest the publicity cost him a publication opportunity through public disclosure. The projected *Nature* or *Science* article was expected to be both a mark of scientific achievement and a driver of investment in the firm.

When knowledge married capital

The growth of a knowledge-based economy and society, currently achieving critical mass, has had a long gestation period. University training in the sciences and research focused on useful properties of natural phenomena as well as theoretical advance merged with industry's interest in appropriating the results of research in house and from external sources created the first systematic wave of university-industry relations in the late nineteenth century in the chemical, metalworking and emerging electrical industries. Professors were closely involved with industrial researchers who were often their former students. Industries supported academic departments in their field of interest and knowledge flowed from academia to industry as problems were brought to academic advisors for solution. Large firms often look back upon this era as the golden age of "university-industry marriage" before universities sought to transfer intellectual property though contractual arrangements and before start-ups became the preferred mode for capitalization of knowledge.

Some earlier relations of industry to the university appeared to be contradictory to the basic research purpose of the research university since they involved highly directed forms of applied research. Much of the current involvement with industry appears to be more compatible with the traditional commitment of the research university to the advancement of knowledge, since basic research is often the source of the invention. There are also occasional large transfers of funds to the university for collaborative research with the expectation that the arrangement will eventually generate useful results. Indeed, the problem with some of these arrangements is that the original funder has been slow to take up the results as, by the time they appear, company interests may have changed. Thus, there is an enhanced use of the start-up firm as an intermediary switching mechanism to identify interested users among large firms.

Maintaining the commitment of knowledge-capital marriage requires an organizational structure with the ability to develop market and improve a product. Even when begun as not-for-profit groups for this purpose, such organizations tend to develop into firms over time. Assuming a level of success as a continuing enterprise, a firm has the ability to set in motion a self-generating process of knowledge and capital creation as opposed to the early stages of capitalization of knowledge that occur as discrete events. Thus, a self-generating and regenerating entity is the typical entrepreneurial objective. However, the very strong point of a firm, its ability to tightly focus on a specific objective, even if not always followed in practice, is also its Achilles heel in the long run.

Firms tend to become committed to their existing technologies, like Kodak to film. Even though Kodak made significant inventions and held considerable intellectual

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properly rights in digital photography, it was never able to wholeheartedly commit itself to developing the new technology for fear of cannibalizing the old, with resulting profit loss, at least in the short, and even medium, run. This is a general drawback that very few firms are able to overcome. Thus, there is a tendency for new firms to replace old ones, as evidenced by the turnover in the members of the Dow Jones index. On the other hand, many of the same universities that were leading institutions in the 1920s are still at the top of league tables today. Think US Steel versus Harvard, Kodak versus Stanford as exemplars of senescence and decline and creativity and longevity.

Renewal is exceptional for companies where as it is the norm for universities: the very weakness of firms is the stellar strength of universities. Universities by their very nature, at least since the post-medieval era, are not committed primarily to maintenance of existing or retrieval of ancient knowledge but are ever more focused on creating new knowledge. That is where the highest academic rewards reside, both in renown and reputation as well as in the new arena of pecuniary advantage. Achieving both objectives at one and the same time is the new academic golden rule. Fred Terman, the noted Provost of Stanford initiated a "steeples of excellence" strategy in the 1950s and 1960s, raising his university from a middling institution to a world class university by seeking to hire faculty members who shared tightly focused interdisciplinary research interests in emerging fields with both theoretical and practical potential. Karl Compton, President of MIT, from the 1930s to 1950s followed a similar strategy in hiring physicists who had achieved research distinction through their traditional academic work but were also patent holders. Jointly achieving these two increasingly interrelated objectives gives the university an enhanced role in innovation, with potential for both collaboration and competition with firms.

The commitment to new knowledge makes the university a formidable competitor in a knowledge-based economy and society, where improvement and replacement of the old by the new is the nature of the game. This is why firms with strong commitments to existing technologies are increasingly concerned that academic researchers may subvert the base of their companies by coming up with a better alternative. Heretofore, firms only feared other firms as competitors. Now they increasingly have to take universities into account in their strategic plans, as well. This is one reason why the technology transfer profession has grown even more rapidly in industry than academia. Traditionally oriented to licensing technologies from other firms, companies are increasingly focused on universities as a potential source of new technology. The Licensing Executive Society, primarily representing company technology transfer officers, has almost 5,000 members, a significantly larger number than the more than 3,000 members of AUTM, its counterpart academic association. As firms have moved to engage more closely with universities; universities have moved closer to industry, by establishing relations with existing firms and by flirting with firm formation.

There is a movement not only towards university and industry collaborating with each other but also through internal changes that leads them to take on some of each other's characteristics and roles. Universities begin to act like a business in commercializing inventions. Businesses begin to act like universities, not only in developing knowledge and training to higher levels but also in adopting some of the ethic of the university, in sharing knowledge. Collaborative projects, often organized under the aegis of an academic research center allow firms to pool their knowledge. Rather than keeping it all secret

within the firm, pre-competitive knowledge may be shared among a group of firms that collaborate to develop research and sometimes products cooperatively.

As innovation more and more takes place in the space between organizations than within them, companies play new collaborative, roles in addition to the competitive ones that they have played before. That is why we are discussing a new role for firms in clusters rather than operating as individual entities. How to cooperate and collaborate while still maintaining the unique features of each firm but also finding that there are advantages to collaborating, not only with similar firms as in a traditional industrial confederation but also with different types of firms from which new ideas can be gained so that the level of the firm can be raised to a higher technological level and new products developed out of these hybrid arrangements.

The birth of academic enterprise

University involvement in technology transfer and firm formation originated in the realization that further steps were often required to bring discoveries into use than simply making knowledge freely available. Indeed, a recent instance illustrates this historical phenomenon. Even though a researcher placed a set of plans for construction of an innovative biotechnology device on his academic web site, making it freely available to all comers, he found that there was little or no take-up. It was not until he identified a PhD student in engineering who was interested in starting a firm that the innovative device was constructed and marketed. At that point, a large firm that had previously turned down an opportunity to license the technology from Stanford University then claimed that it had played a role in its invention and attempted to gain control of the device through the legal system. In the end, the large firm purchased the start-up, implicitly recognizing the superiority of the firm-formation process over licensing in developing early-stage advanced technology, despite the seemingly higher cost.

What is significant in this instance is that knowledge, by itself, is rarely so compelling as to insure its utilization. Further steps must be taken. An organizational process of carrying the development of knowledge forward towards utilization is typically required. While some academics have the access to social and financial capital to organize this process themselves, most need additional support, whether for profit-making or non-profit ventures (Etzkowitz, 2013). The increased involvement of the university in technology transfer has internal consequences, resulting in a higher level of organized activity to conduct business and manage relations.

Insuring ethical manufacture is another impetus to technology transfer and the birth of enterprises under academic supervision. The discovery of insulin by researchers at the University of Toronto in the early twentieth century impelled a university that heretofore had little or no interest in technology transfer to patent and license this discovery in order to insure ethical production. Similarly, the University of Wisconsin realized that it would be held responsible by the public if a test for milk purity invented on campus was marketed without insuring reliability and safety. To insure protection of the university's good name as well as to facilitate technology transfer, the university created an organization to vet and control how the useful results of academic research were marketed. Initially, the invention of a new scientific instrument or software is shared with a few trusted colleagues. But when demand increases, there is a need for an organization to undertake manufacture, distribution and customer support.

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Once technology development goes beyond the earliest phases, the risk is that the efforts of a lab will be diverted form research to development. Organizational division of labor, resulting in the birth of enterprises from academia is one solution to organizational overload as well as a contribution to economic and social development.

The start-up, arising from a conjunction of intellectual, social and financial capital is the organizational hero of the knowledge age. The high-tech start-up is a transmutation machine for changing intellectual into financial capital. Sometimes, it is intended to grow into a large-scale organization; other times to be the vessel of a technological or business innovation that will eventually be sold to a larger firm: either strategy is always subject to change. A firm finding that its independent strategy is not working may identify a larger firm that may find it useful in improving the productivity of its existing business. For example, a firm that was established to commercialize a process that improved solar cell efficiency by 10 percent found that it was not possible to create an independent product on this narrow base. However, by selling the firm to Dupont, where the technology could be utilized to improve that large firm's production processes, a broader utilization could be achieved. Thus, a start-up firm, with a discrete incremental innovation, succeeded even though it did not become a viable independent entity.

Innovations, like Google's search engine, have become the basis of start-ups that have grown into major firms. Other firms are formed to develop university originated technology with the intention of being purchased eventually. Rather than licensing an early stage technology directly to a larger firm, where it may or may not receive proper attention for development, it is more productive to create a start-up, which will give the invention its sole and undivided attention. If the development process works, the firm can then be marketed to a larger firm. For example, the SIRI personal assistant software, which came out of the University of Delaware, moved forward as a start-up before being purchased by Apple.

University-industry relations take place both through formal and informal means. In countries where there are not yet formal linking mechanisms like technology transfer offices, there are often informal connections which can be seen as a kind of underground economy, going from teachers to students. In nineteenth century Germany students, advised by their professor, founded many of the firms in the chemical and optics industries. Thus, in a contemporary presentation by representatives from Jena Optics, there are three people on the screen: the professor, the student and the person who financed the firm. Nineteenth century technical industries typically originated through these kinds of informal connections, providing social capital, which was transformed into firms and financial capital.

More recently we have seen formal relations, conducted by organizations within the university that have responsibility for seeking out research results that can be commercialized. By engaging in these activities the university takes on some of the attributes of a business. Initially this happens within a discrete part of the university, typically in the engineering or medical school as an apparently spontaneous event. Next, the process is institutionalized through a special office that seeks out members of the faculty who have research with commercial potential. Sometimes, when a faculty member is first approached, they had not thought of commercializing their research. It is a new idea to them. Stephen Atkinson, who founded Harvard's technology transfer office in 1976, soon showed up at the offices and laboratories in the molecular biology department and suggested that research work could be patented. Faculty members

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were skeptical at first but when it was explained to them that they could publish their articles, that there was a year for the patent to be filed. They said, why not?

Changes in the knowledge production, application and distribution institutions

The expansion of the university's economic role is paralleled and supported by improvements in the production and distribution of knowledge. The function of knowledge in society and the social role of the knowledge creator have evolved from its cultural origins into a central feature of the economy. The secularization of knowledge production from its magical and religious origins culminated in modern science that has expanded from a limited number of areas into a highly differentiated enterprise. The quantification of data (Dijksterhuis, 1961) the specialization of knowledge into professionalized disciplines (Ben-David, 1972) and the exponential increase in scientific publications (Price, 1963) has made knowledge production an economic activity in its own right with measurable "inputs" and "outputs" (Machlup, 1962). Its practitioners have grown from a small number of persons into a measurable and significant proportion of the population (Bell, 1976).

Two theories of social and scientific transformation, Marxian and Kuhnian, may be utilized to frame these developments. In Marx's view, capitalism lives on within the context of socialism, even as it is transformed. Despite each revision, the university retained its old tasks while taking up the new. On the other hand, in Thomas Kuhn's view of scientific revolutions the old mode of science is forgotten as it is displaced by the new. In the development of university, the innovations of successive eras – research as an end in itself and knowledge for economic development – persist in tension with each other. In that respect the academic revolutions have been "Marxian" in style. There is also a certain loss of memory that the academic enterprise, especially in the sciences, was virtually a different species prior to the Second World War and the advent of federal research funding. In this respect the academic revolutions, incorporating research and then economic and social development as university missions, are akin to a Kuhnian paradigm shift (Kuhn, 1962).

Heretofore, the cultural functions of teaching and research have been the primary legitimation for universities while a human capital function of preparing trained persons has played a supporting role. As universities increasingly come to be viewed by political leaders, industrialists and university administrators as focal points of industrial development for regional economies economic legitimating themes are becoming as important as cultural ones. As university based scientific research increasingly becomes the source of new companies and new jobs; the university is drawn into an ever-closer relationship with corporations and governments (Stephan, 2012). These have been the core institutions of modern society, since the eighteenth century, and as the university helps create the framework of an emerging knowledge-based society, it becomes a core institution itself. This enhanced role of the university is the premise of the Triple Helix model of university-industry-government relations that explains the dynamics of a knowledge-based society (Etzkowitz, 2008).

Academic institutions have gradually moved from arms length relationships to closer forms of economic involvement. Universities are increasingly looking to take additional steps to commercialize the research results of their faculty, going beyond simple licensing to support translational research and the initial stages of firm formation.

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This is done both to assist local economies create new economic activity and jobs and, hopefully, to help finance the academic enterprise in the longer run. Communities that once were dependent on student enrollment to drive the purchase of goods and services now look to the transfer of knowledge and technology from university to firm and the formation of high-technology companies near the campus as the driving force of their economic base.

Indeed expectations of economic effects from universities have extended beyond the sciences and engineering into the humanities and the arts. University sponsored cultural activities and arts spinoffs from academia also drive economic activity like tourism. Indeed, the campus itself may be an attractor of visitors, well beyond prospective students, who wish to view the campus and have their photos taken in academic surroundings. Special parking areas for tour busses have been established at Stanford University, for example, to accommodate visitors and free tours of the campus are available. Thus, academic ambiance and aura as well as academic knowledge and technology stimulate local economies.

Universities are usually thought of as a conservative institution, originally established to pass on the traditions of societies, not as having an entrepreneurial ethos. Indeed, entrepreneurship and academia might be considered to be an oxymoron, an inappropriate pairing of concepts. Although the contemporary university is a great distance from its medieval origins, it can be recognized as performing a basically similar task as its predecessor. It is the same institution, comprising teachers and students, oriented to a common goal of knowledge production and transmission. On the other hand, the contemporary university has a distinctly different look and feel, even from a few decades ago. Its administrative structure often includes business capacities to organize technology transfer and a significant number of faculties have expanded their focus to include attention to the marketable as well as publishable results of their research.

The reorganization of the university is more fundamentally driven by changes in knowledge production and utilization as new forms of knowledge are created through the intersection of academic, industrial and government interests. A new set of scientific disciplines has recently been created that simultaneously exhibit both theoretical and practical implications, rather than the latter emerging after a long time delay. Thus, scientific disciplines themselves today, especially the most important emerging ones, molecular biology, computer science and materials science mean that the attainment of theoretical advance is closely related to technological innovation and vice versa. The synthesis of new fields focused upon novel objectives, like bioinformatics, from elements of previous interdisciplinary syntheses, drives both the advancement and capitalization of knowledge in an ever-increasing spiral.

Conclusion: symbiosis between knowledge and capital and the future of enterprise

There is a symbiosis between knowledge and capital – various capitals: economic, human and intellectual are required to create knowledge and knowledge itself is a basis of capital accumulation. In a spiraling progression that feeds upon itself, the knowledge/capital dynamic is the basis of future economic and social development. Enterprises are increasingly the instantiation of a theoretical concept and knowledge and its permutations are the source of the diversification of enterprise. The growing

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awareness of the potential utility of basic research suggests that the new forms of university-industry relations will be more pervasive and important to both institutional spheres than traditional connections more directly focused on the solution of industrial problems (OECD, 1984). The paradox of university-industry relations, in the transition from an industrial society, is that the number and types links of university-industry links increase as basic, rather than applied research becomes more salient to economic development in a knowledge-based society.

In Weber's pessimistic vision, the university as one of the last interstices of modern society relatively free from bureaucracy was inexorably being incorporated into the system with an expected loss of autonomy and rise of alienation. He argued that scholars would lose control of their means of production as the scale of research tools increased. Indeed, alienation of investigators from their research tools has occurred in many laboratories. Academic scientists can more often be found in their offices and students and technicians in the laboratories. However, as these researchers have given up direct control of the means of research production, they have become centrally involved in creating a new industrial means of production from their research. The scaling up of academic science, in selected areas during the Second World War, supported by government funding that continued after the war transformed additional areas of small science into a more organized mode.

The dependence of scientists on large-scale research tools that they do not own themselves is even greater today than in Weber's time. Alienation of investigators from their research tools has occurred in many laboratories as academic scientists can more often be found in their offices and students and technicians in the laboratories. However, the outcome is contradictory as the capitalization of knowledge has superseded the proletarianization of scientists as a central issue. As academic scientists have given up direct control of the means of research production, they have become centrally involved in creating a new industrial means of production from their research. This transformation of the university into an engine of economic development brought with it a shift in values that are still underway. Academic-industry relations provide a litmus test of a university's goals. Just as a litmus test partially turns color-indicating degree of acidity, conflicts over relations with industry signal the stage of transition that a university is in, shifting from a feudal to a capitalist mode of production. Conflicts that arise over the terms of engagement between university and industry may be taken as an indicator that transition to an entrepreneurial university model has been broached, even if it has not yet been accepted.

Entrepreneurial science, aside from a few anomalous instances, was earlier inhibited by norms that oriented basic research scientists in universities to the production of knowledge as an end in itself. The means used to reach that end had the consequence of displacing the individual investigator by the research team as the modal form of research activity, irrevocably altering the social structure of science. The entrepreneurial university has not yet found its distinctive metaphor. Nevertheless, in form and substance, and as a collectivity of institutions, American universities are approaching the Baconian ideal of "Solomon's House", a multi-purpose theoretical and practical research and development agency for their society. The organization of group research in industry and university during the twentieth century and the linking of academic research to industrial uses have brought Bacon's dream closer to reality.

The creation of academic-industry ties is redesigning Solomon's House into an even more capacious mansion – the contemporary entrepreneurial university.

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